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An innovative approach to automate BIM data retrieval and processing for building acoustic comfort calculations based on the IFC standard

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ABSTRACT

Nowadays, there is a growing demand for deep renovation projects aimed at improving the energy efficiency of buildings while enhancing indoor comfort conditions for the inhabitants, both thermal and acoustic. To design effective renovation strategies, technicians need to know the current state of the building to propose acoustic or only thermal improvements. However, evaluating indoor acoustic comfort requires time-consuming and tedious calculations, which can be prone to errors when handled manually. While Building Information Modelling (BIM) can facilitate this process by leveraging the extensive contained data and offering the potential to automate these processes, such automation is not yet widespread. Typically, only geometric data is retrieved automatically from BIM models in acoustic software, while acoustic parameters must be provided manually. This paper addresses these challenges by introducing a novel approach that integrates automated data extraction from BIM with acoustic simulation tools. Specifically, an Extract, Transform and Load (ETL) solution was designed to automatically retrieve both geometric and acoustic data for an Acoustic Comfort tool, which calculates an estimation of indoor acoustic comfort, from an Industry Foundation Classes (IFC). This approach was tested in a demonstration case located in Spain, showing a significant reduction in processing time and increased accuracy compared to traditional methods of manually extracting data from BIM for acoustic assessment. This research represents a significant advance in acoustic simulations by integrating IFC data with automated processing, improving accuracy and offering practical advantages for developing more efficient and reliable BIM-based applications, thus supporting the design of deep renovation projects.

1. Introduction

Most of the buildings in the European Union were built between 1961 and 1990 or before the 1960s [1], which makes them low energy efficient buildings, resulting in low indoor acoustic and thermal comfort. Consequently, deep building renovations are on the rise today, and will increase in the coming years, mostly motivated by new European regulations to improve energy efficiency [2,3], which also allows the acoustic performance of the building to be improved. Technicians in charge of deep renovation projects need to know all the preconditions existing in the building at the design phase to adapt the proposed solutions to the renovation project. The adoption of Building Information Modelling (BIM) can facilitate this decision-making process, thanks to the large amount of data that they can contain [4,5]. While the adoption of BIM has grown in recent years, its full potential, particularly in terms of time reduction and accuracy, remains underexplored. Moreover, current applications are primarily focused on enhancing the thermal aspects of renovation, with limited attention given to acoustic assessment [6–9]. The combination of design and acoustic analysis in the same digital environment such as BIM is of great interest nowadays [10], where the development of Digital Building Twins (DBT) has become more and more extended [11]. Different acoustic parameters can also be included in a BIM model according to the Industry Foundation Classes (IFC) data exchange standard, ISO 16739:2013 [12], such as the acoustic rating information of building elements and the external noise level of the street, but there is a lack of interoperability between acoustic simulation software and BIM models.

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Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
$\Delta L_{f\ s}$	Level difference due to façade shape
BAS	Building Automation System
BACN	Building Automation and Control Network
BIM	Building Information Modelling
C#	C Sharp (programming language)
CSV	Comma-Separated Values
dB	Decibels
$D_{2m,nT,w}$	Weighted standardized sound level difference of façade [dB]
DBT	Digital Building Twins
FM	Facility Management
GUI	Graphical User Interface
GUID	Globally Unique Identifier
HVAC	Heating Ventilation Air Conditioning
IAQ	Indoor Air Quality
IFC	Industry Foundation Classes
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
HTTPS	Hypertext Transfer Protocol Secure
JSON	JavaScript Object Notation
MEP	Mechanical, Electrical and Plumbing
ML	Machine Learning
MVD	Model View Definition
$L_{1,2m}$	Average sound pressure level at 2 m in front of the room façade
L_{Aeq}	Indoor A-weighted equivalent sound pressure level dB(A)
O&M	Operational & Maintenance
Pset	Property Set
RT	Reverberation time
R'_w	Sound reduction index
$R'_{w\ i}$	Sound reduction index of element
SPL	Sound Pressure Level
XLS	Filename Extension [Microsoft Excel spreadsheet file]

In this context, the objective of this research paper is to introduce an innovative approach for the automation of BIM data retrieval and processing towards its application for building acoustic comfort calculations. This will contribute to overcome key challenges of tedious and error-prone common practice in acoustic data management within the built environment.

The proposed methodology has been developed within the framework of the BIM SPEED [13] research project, which aims to overcome existing barriers in deep building renovations and reduce project timelines thanks to BIM-enhanced processes. Specific objectives pursue time reductions for the acquisition of real (As-Built) building data using BIM, as well as for the design and detailed engineering of the proposed renovation solutions [14]. Thus, the obtained results will enable technicians involved in deep renovation projects to make informed decisions during the design phase, supporting acoustic comfort enhancement inside buildings.

The core of this innovative approach is implemented in an Extract, Transform and Load (ETL) solution, the IFC4Acoustic parser. This solution uses an IFC-based BIM model as the input data source, addressing interoperability challenges by leveraging the IFC standard, and proposes an automatic transformation of the acoustic data included in the IFC file of the building into the required input format for acoustic performance assessment tools. Moreover, while the methodology developed in this research is demonstrated using an Acoustic Comfort tool [15–17], which calculates an estimation of the indoor Sound Pressure Level (SPL) according to EN ISO 12354-3 [18], it is designed with flexibility in mind, allowing for adaptation to other acoustic assessment tools and workflows.

Section 2 gives an overview of the state of the art of existing BIM-based acoustic simulation methods, identifying the research gaps addressed by this work. Section 3 explains the methodology followed throughout the complete process of retrieving BIM data for acoustic comfort calculation using the IFC4Acoustic parser service, emphasising its potential adaptability to different tools and applications. Section 4 presents the results of the application of the tool in a real demonstration case and a manual validation of the tool. Section 5 shows the discussion about the results including a comparison with the common practice for the process of retrieving BIM data. Finally, conclusions are outlined in Section 6.

2. Overview of BIM-based acoustic simulation methods

2.1. Automating BIM-based data collection for acoustic simulation

In recent years, the adoption of technologies, such as BIM, for the digitalization of the built environment has become more widespread, which has led to the development of new BIM-based tools for the purpose of exploiting the potential of the large amount of information contained in BIM models [19,20]. These tools are usually focused on energy simulations [21–24] or in the digitalization of the buildings to obtain the As-built models [25,26]. There are some developments specialised in the acoustic analysis using BIM models as input data, but BIM-based tools dedicated to automating the data collection processes to perform acoustic assessment of a building have not been extensively implemented in the past, as shown in previous literature reviews [10,27]. In Ref. [10] it is considered that BIM models contain a complexity and an excess of information that have hindered the development of BIM-based tools for acoustic calculations, requiring significant simplification while maintaining the integrity of the analysis. Harvey in Ref. [28] focused its work on identifying measures that can be taken to mitigate the poor acoustic performance of buildings, as well as the interoperability of existing acoustic simulations tools with BIM authoring tools. Works like [29–32] oriented their research towards the calculation of the reverberation time (RT) and Schroeder's frequency using REVIT [33], a BIM software, and a script in Dynamo, a visual scripting, to calculate the Indoor Environmental Quality (IEQ). The algorithms developed in Dynamo calculate the RT, retrieving the geometric data of the spaces directly from the BIM model in REVIT. The methodology proposed in Ref. [29] requires a manual process by the user to select rooms one by one to perform the calculation for each room, or to discard non-selected rooms, as well as manually select the materials for each wall or window from a pop-up screen, being a semi-automatic process. A similar approach was adopted by Nik-Bakht et al. in Ref. [30] and Erfani et al. in Ref. [31]. In both cases the absorption coefficients of the materials are obtained by automatic connection to an external database with information on common materials, while in Ref. [29] a more manual process was followed by the selection of materials. In the case of Aguilar et al., the research in Ref. [32] focused on the development of a BIM-based framework for RT to analyse, evaluate and optimise the acoustic performance, considering the limits set by the regulations. The work of Tan et al. in Ref. [34] was oriented again towards RT, with the aim of evaluating and improving indoor acoustic performance of a concert hall, but in this case considering an IFC file as input, and supporting the acoustic analysis performed with commercial finite element solvers, e.g. the one implemented in COMSOL Multiphysics. It should be noted that the use of finite element methods for the acoustic comfort assessment is time-consuming and does not contribute to increase the accuracy of the results. The architectural geometry, decorated materials information, and speaker location needed for acoustic analysis were obtained directly from the IFC file and connected to the acoustic tool through an API connection and using a Java class file. The geometry of the concert hall was obtained using the *IfcSpace* entity, and the absorption information of the materials was assumed based on the type of walls and elements of the space. In Ref. [35] a BIM-based prototype application was developed to perform acoustic simulation based on the RT and sound intensity level, using the REVIT API to retrieve the BIM data, programmed in C# language. The extraction module developed with the API of REVIT retrieves all the room information to perform the reverberation calculation, materials, and their surface area, in a spreadsheet, and depending on the type of wall finishing materials, the software adds material absorption coefficients. It also gives information about the presenter's location in the room with x, y, z coordinates. Moreover, in this case, the selection of the rooms for the calculation is done manually by the user, as well as the configuration of the different frequencies to be analysed. Mastino et al. in Ref. [36] developed a calculation code in C++ and C# programming language for IFC-based predictive acoustic analysis in the design, construction and completion phase of the building, enabling to analyse the geometry of the pre-defined acoustic zones. The computation model was defined to create a user-defined Property Set (Pset) for each of the main elements of the BIM model (spaces, walls, slabs, roofs, doors, and windows) including the results of the predictive calculation, and assign each Pset to the BIM model elements, in this step in the authorising BIM tool, without using the IFC.

There is also research that focuses on the context of building services and flow distribution systems for the calculation of noise in the building facilities, such as that conducted by Marini et al. in Ref. [37]. They analyse the datasets provided by the *Pset_SoundAttenuation* and *Pset_SoundGeneration* of the IFC standard. Mastino et al. in Ref. [38] explored the requirements and characteristics needed to perform acoustic and energy simulation considering the IFC class structure. Some of these requirements that need to be met when using IFC models for acoustic simulation include: appropriate models and geometry, with correctly defined and identified spaces and zones (definition of uses, correct identification of exterior walls, etc); correct integration of non-BIM data; and correct definition of BIM objects (e.g., thermal resistance.) An analysis of the gbXML [39] format was also done in Ref. [38]. Pauwels et al. in Ref. [40] implemented a proof of concept of an acoustic semantic rule checking for acoustic performance testing. To support the proposed rule validation, and to address the limitations of the IFC standard, the IFC was transformed to Resource Description Framework (RDF) format [41], using graphs as the semantic web language for this transformation.

Table 1 summarises the findings from the literature review, providing an organised overview of the current state of the art in the field of BIM-based acoustic assessments. The table maps the key information requirements necessary for acoustic assessments to the specific tools and methods used to extract this data, indicating whether these processes are manual or automated. The information requirements considered in this comparison include building/room geometry (such as dimensions and spatial relationships) and material properties (e.g., sound absorption coefficients, transmission loss, and material density).

2.2. Identifying research gap and contribution

Based on the previous literature review, summarised in Tables 1 and it is not common for acoustic software to retrieve acoustic data from a BIM model in an automatic way, where only the geometrical side is supported and the acoustic parameters have to be included manually.

Table 1
Summary of information requirements, tools, and extraction methods for BIM-based acoustic assessments.

Tool used in previous studies	Extraction method		Details/comments	Reference
	Building/room geometry	Material properties		
REVIT + Dynamo	Semi-automatic	Manual	Geometric data is automatically retrieved; manual room and material selection is required	[29]
REVIT + Dynamo + External database	Semi-automatic	Automatic	Geometric data is automatically retrieved with manual room/floor selection. Material properties are automatically retrieved from external databases linked to the BIM model.	[30–32]
REVIT API	Semi-automatic	Automatic	Room geometry and material areas are extracted automatically; manual room selection by the user is necessary.	[35]
IFC-based tools + COMSOL Multiphysics	Automatic	Manual	Geometric data obtained from IFC files; integration with acoustic tools via API requires manual setup.	[34]
IFC-based tools + calculation model based on C++ and C#	Automatic template generation, manual data entry	Manual	Both the geometric data and material properties need manual input during the survey phase.	[36]

Previous research, such as that conducted by Sušnik et al. in Ref. [29], addresses the process of including acoustic data, but using a BIM authoring tool as REVIT and Dynamo (used as a Graphical Programming Interface), not supporting the IFC standard. Even so, the tool requires user interaction to manually include wall and windows materials, duplicating user effort when this information is already included in the elements in BIM. In the development carried out in Ref. [35] a manual interaction by the user is also necessary to select the room in which to perform the analysis, once again using the REVIT software, in this case through its API. Another problem to consider is that some acoustic simulation tools do not correctly analyse the geometric information contained in an IFC file, as in the case analysed in Ref. [29] using the IES VE tool, with differences in the calculation of the dimensions of the spaces, due to problems with the representation of the bounding surfaces, affecting the calculation of the volumes. It should be noted that the IFC format was not used as core in Ref. [29], but tests were made when exporting to IFC and subsequent analysis of the model obtained with the IES VE tool. There is a notable lack of research on fully automating the extraction and use of data using the IFC standard as input for acoustic simulations. Some of the limitations that exist when using IFC models as data input for acoustic simulations where collected in Ref. [38]. This lack represents an opportunity to develop methods to streamline and improve the accuracy of acoustic performance assessments to improve building renovation projects, while also using data based on IFC, the most widely used standard for BIM modelling.

Based on the literature review, key issues have been identified in the widespread implementation of BIM-based tools for automating acoustic assessment. The complexity and excess of BIM data information is one of them. This complexity has been a significant barrier to the development and implementation of BIM-based acoustic tools. Another cause is the difficulty of mapping BIM data, in particularly acoustic parameters, into formats that can be directly utilised by acoustic simulation tools. The lack of standardisation and interoperability between BIM software and acoustic assessment tools has further increased these issues, leading to a reliance on manual processes and limiting automation.

The ETL developed in this research, the IFC4Acoustic parser, addresses these challenges by fully automating the retrieval and processing of both geometric and acoustic data directly from IFC-based BIM models. The ETL performs an automatic mapping between the BIM model of a building and an existing Acoustic Comfort tool, using an IFC file as input, and generates an output that follows the JSON structure used as input by the Acoustic Comfort tool. This connection between the two tools is done through an Application Programming Interface (API). The solution proposed in this research which combines the IFC4Acoustic parser with the Acoustic Comfort tool, represents an advantage over the state of the art on this field since most software dedicated to acoustic calculations is not compatible with the IFC standard [29–32,35]. Only a few studies, such as the work of Tan et al. in Ref. [34], used an IFC file as input data, but with the objective of calculating the reverberation time (RT), which is considered a limited calculation for indoor acoustic comfort assessments. Moreover, Mastino et al. in Ref. [36], developed an IFC-based computational model for predictive acoustic analysis, which also includes calculations for Sound Pressure Level (SPL). The system automatically generates an Excel template based on the IFC file, but the data must be manually entered into these templates during the on-site survey.

Although both the SPL and the RT are acoustic parameters used to characterise sound in the space in which it propagates, the two parameters have different considerations. The acoustic comfort of a room can be seen as the sum of two main factors. The first one is related to the efficiency of the envelope of the building in which the room is located in filtering out external noise. In that sense, the SPL [42] measures sound intensity in decibels at a specific point, considering factors such as the distance from the sound source and the absorption and reflection of sound by intermediate objects, such as building envelope elements. If the building envelope is acoustically efficient, the indoor SPL will be low even in the presence of high outdoor noise. The room comfort can be therefore calculated as indoor SPL. The second factor influencing the acoustic comfort in a room is the RT, i.e. the time required for a sound, when suddenly interrupted, to decay to a level 60 dB below the original sound [43]. This represents the performance of the room in enhancing the sound perception. The RT depends more on the geometry of the room and on the coating materials of the walls and ceiling and floor rather than the building envelope. The Acoustic Comfort tool considered here calculates both indoor SPL and RT indicators. However, this research focuses on SPL, as our main interest is the building envelope and interventions that can enhance indoor comfort, even though the building is located in a highly noise-polluted district. The studies found in the literature do not cover the calculation of the indoor SPL. However, we identified one study in Ref. [36] that considers it, but without automating the process, which is the focus of this research.

Summarising the contributions to the state of the art with this research are focused on.

- BIM-based calculation of indoor acoustic comfort in relation to building envelope for renovation scenarios optimisation, based on the IFC standard.
- Integration and automatisation of a BIM data parser with an acoustic comfort tool for indoor SPL estimation based on outdoor noise strategic map or available acoustic measurements, designed to automatically retrieve both geometric and acoustic data.

3. Materials and methods

The methodology followed in this research was divided into 3 steps. The first step involved classifying all the input data required by an acoustic software tool to perform the estimation of indoor acoustic performance, ensuring compliance with existing acoustic regulations. Although the methodology was demonstrated in this research using the Acoustic Comfort tool, the approach is generalised for broader applicability. Following this, the input data required were mapped to their corresponding data that can be found in an IFC file. For this purpose, a study of the IFC standard was done in this step, in order to define all the possible casuistries that can be found for the same parameter. The next step in the research was to define the structure of the ETL solution implemented, focusing on identifying the necessary functionalities and features to meet the requirements of a wide range of acoustic software tools, as detailed in Section 3.2. The Application Programming Interface (API) used to connect the ETL with the Acoustic Comfort tool is outlined in the following sub-sections. As a final methodological step, the developed process was tested on a real demonstration case. This is presented in Section 4.

3.1. Input data requirements for acoustic comfort calculation

The Acoustic Comfort tool used in this research performs acoustic calculations to estimate the indoor sound pressure level in accordance with EN ISO 12354–3:2017 "Building acoustics: Estimation of acoustic performance of buildings from the performance of elements. Part 3: Airborne sound insulation against outdoor sound", a regulation that applies to the design, construction and renovation phases. The regulation EN ISO 12354–3:2017 specifies a calculation model for the estimation of the sound pressure level inside the building considering the external noise, the weighted standardised façade level difference ($D_{2m,nT,w}$) Eq. (1). This estimation considers the sound pressure levels measured outside the building, as well as the data characterising the sound transmission through the relevant elements and openings in the building envelope. The estimation of the external noise is one of the main sources of uncertainty in the calculation of indoor sound pressure level [15], with a sensitive rate of more than 80 %. The use of strategic noise mapping provides indoor level predictions with an uncertainty of around 6 dB, as it samples large areas where noise can fluctuate from the mean value. Consequently, an evaluation of the measured external noise levels directly in front of the building façade is beneficial to improve the confidence in the estimation of the acoustic performance of the building.

The general procedure for the acoustic performance calculation of the Acoustic Comfort tool is based on the following steps (divided at room level and at building level).

- **Room-level**: (i) direct measurement of the external noise level. If there is a strategic noise mapping available, the external noise level is obtained therefrom, otherwise a direct measurement of the external noise level is required; (ii) calculation of the standardised sound level difference of the room façade based on the knowledge of its material layers and the façade elements available in the BIM model, Eqs. (1)–(4); (iii) evaluation of the equivalent continuous sound pressure level ($L_{A,eq}$) Eq. (5); (iv) assignment of the room acoustic class, assigned after estimating the equivalent continuous sound pressure level of each room bordering the external environment following a range of values established for each type of room, from class A to E [15].
- **Building-level**: (v) analysis for the building acoustic class assignment.

The room façade standardised sound level difference and the evaluation of the indoor equivalent sound pressure level are calculated with the equations defined below, according to the Annex E of EN ISO 12354–3:2017. The weighted standardised façade level difference is calculated as shown in Eq. (1):

$$D_{2m,nT,w} = R'_w + \Delta L_{fs} + 10\log\left(\frac{V}{6 \bullet T_0 \bullet S}\right)[\mathrm{dB}] \quad (1)$$

where R'_w is the façade sound reduction index [dB], used to determine the noise difference between the exterior and the interior, calculated according to Eq. (2); V is the volume of the receiving room [m^3]; T_0 is the reference reverberation time [s] (generally 0.5 s for dwellings), S is the total area of the façade facing the inner part touching the room [m^2]; ΔL_{fs} [dB] is the level difference due to the shape of the façade (e.g. balconies), with respect to the central face of the façade.

$$R'_w = -\ 10\log\left(\sum_{i=1}^{n}\frac{S_i}{S}\,10^{\frac{-R_{w,i}}{10}} + \sum_{i=1}^{n}\frac{A_0}{S}\,10^{\frac{-D_{n,e,w,i}}{10}}\right) - K\,[\mathrm{dB}] \quad (2)$$

where R'_{wi} is the sound reduction index [dB] of the element (i), calculated according to Eq. (3), and S_i the area of the element (i) of the façade [m^2]; S is the total area of the façade facing the inner part touching the room [m^2]; Ao is the reference equivalent sound absorption area equal to 10 m^2; $D_{n,e,w,i}$ is the weighted normalised sound level difference of each small element [dB], calculated according to Eq. (4); n is the total number of elements in the façade; and K is a correction factor for the flanking sound transmission [dB].

$$\begin{aligned} R_{w,wall} &= 37.5\log(m') - 42\ [dB] \\ R_{w,window} &= 12\log(m') + 17\ [dB] \\ R_{w,door} &= 20\log(m')\ [dB] \end{aligned} \quad (3)$$

where m' is the mass per unit area of the element.

$$D_{n,e,w} = -\ 10\log\left(\frac{S_{open}}{A_0}\right)[dB] \quad (4)$$

where S_{open} is the area of the small elements [m^2]; and A_0 is the reference equivalent sound absorption area equal to 10 m^2. The equivalent continuous sound pressure level is calculated according to Eq. (5):

$$L_{A,eq} = L_{1,2m} -\ D_{2m,nT,w} + 10\log\left(\frac{T}{T_0}\right)[\mathrm{dB(A)}] \quad (5)$$

where $L_{1,2m}$ is the average sound pressure level at 2 m in front of the room façade [dB]; $D_{2m,nT,w}$ is the weighted standardised façade level difference [dB] Eq. (1); T_0 is the reference reverberation time [s] (generally 0.5 s for dwellings); and T is the reverberation time [s] in the receiving room. Having estimated the equivalent continuous sound pressure level ($L_{A,eq}$) for each room bordering to the external environment, an acoustic class is assigned to the room itself. Acoustic class depends on the space use (offices, bedrooms, living rooms, classrooms, etc.).

All data required as input for Eqs. (1)–(4) will be retrieved from the BIM model of the building with the developed ETL.

3.1.1. Input data acoustic comfort tool

The required data to perform the acoustic calculations by the Acoustic Comfort tool are summarised in Table 2 and grouped according to the level of detail that they provide in relation to different elements of the building. Only the information associated with the rooms adjacent to the external environment is used for the calculations. Considering that the developed ETL needs an input IFC file (IFC4: ADD2-TC1 schema version [44]) as a first step, an analysis was carried out on the data that could be directly obtained from the IFC standard. In the next sub-section, a short guideline is presented on how to model the IFC file to comply with the input requirements of the tool to perform the acoustic calculation. These inputs will also consider the requirements of the IFC models identified in previous works such as that of Mastino et al. in Ref. [38] (correct geometry and semantic data, integration of non-BIM data, thermal properties of the elements, etc.) mentioned in section 2.1.

Table 2
Inputs needed to perform the acoustic calculation by the tool.

Associated element	Input
Building information	District land use (Countryside/residential area/ urban area)
Room information	End use (Bedroom, etc.)
	Volume (m^3)
	Floor area (m^2)
	Shape (i.e., open/closed fence)
	Floor level
	External equivalent noise pressure level (dB)
	Balcony width (m)
	Balcony material
Elements in façade information	Element type (window, door, small element)
	Surface (m^2)
Walls information	Layer thickness (m^2)
	Layer density (kg/m^3)

The structure of the JSON file that will contain the building data extracted from BIM is shown in Fig. 1. This JSON file is required as input data for the Acoustic Comfort tool. For the mapping between the information contained in the BIM model, IFC-based, specific guidelines for BIM modelling have been defined in the following subsection.

3.1.2. Mapped parameters IFC-JSON

The process of mapping IFC data schema to acoustic simulation requirements is shown in Table 3, including the specific attributes and entities involved in the mapping, and how they correspond to the JSON input data structure (defined in Fig. 1).

3.1.3. BIM guidelines

As shown in Table 3, most of the parameters required in the parsing process can be extracted directly from the IFC file, but some of them cannot be mapped directly because the IFC file does not provide the final value required by the JSON file. Other values have been fixed by default as in the case of: *Land use category*; *Strategic Noise Mapping value*; while *Balcony material* and *Balcony width* have a default value of −99. These values have not been characterised in detail because they are not considered critical in many real cases, as in the demonstration case used in this research. The same applies to the *Room shape* parameter, as there is no balcony in the building used for the validation, no closed or opened fence, and all rooms have the same shape of room façade.

Moreover, the following list shows the parameters that should be correctly modelled in the BIM model and usually are not. This is the case, for instance, of the thermal properties of materials. These parameters are.

- **Room Use**: this parameter is needed to categorise the rooms, as each type of room has an associated numeration which is then used in the acoustic tool. For each space included in the IFC file, the ETL retrieves the information contained in the attribute *Name* of each of the *IfcSpaceType* class according to the IFC standard, and then assigns them to the appropriate group number, e.g., Bedroom = 1. The room uses considered are: bedroom, living room, kitchen, hotel bedroom, classroom, nursey school, office, conference room, hospital, and retail shop. The corridors and bathrooms are discarded from the automatic selection. The ETL has been programmed to recognise information on the most common names uses for each type of space and in 4 different languages (English/Spanish/Italian/German), as for instance in this case for the type of bedroom can recognise (EN/ES/IT/DE): *Bedroom/dormitorio, habitación, hab/camera da letto/ Schlafzimmer=1*. It should be noted that only spaces that meet the established requirements will be selected (with regard to the type of use and its location touching an external wall of the building).
- **Party walls**: in these cases, the name *Party_Wall* must be added to the walls in their attribute *Name*.

```
{
    "RoomFacade": {
        "Rooms": {
            "Room use": [… , …],
            "Room volume": [… , …],
            "Room floor area": [… , …],
            "Room shape": [… , …],
            "Room floor": [… , …]
        },
        "District_Land use category": … ,
        "District_Total number of buildings": … ,
        "Building_ID": [… , …],
        "Building_Total number of room facades of each building": … ,
        "RoomFacade_ID": [… , …],
        "Room_ID": [… , …],
        "RF_Surface": [… , …],
        "RF_Strategic Noise Mapping value": [… , …],
        "RF_Balcony material": [… , …],
        "RF_Balcony width": [… , …],
        "External equivalent sound pressure level": [… , …]
    },
    "ElementFacade": {
        "Wall": {
            "Number of wall id": … ,
            "Wall id": [… , ...],
            "Wall layer thickness": [… , ...],
            "Wall layer density": [… , ...],
        },
        "Element Building_ID": [… , ...],
        "Element RoomFacade_ID": [… , ...],
        "Element type": [… , ...],
        "Element surface": [… , ...],
        "Element id": [… , ...],
    }
}
```


Fig. 1. JSON structure. Note: RF=Room Façade.

Table 3
Mapping between the JSON parameters and the standard IFC.

JSON parameter	Ifc class (entity) or fixed parameter
RoomFacade	
Room	IfcSpace/GlobalId
Room use	IfcSpaceType
Room volume	IfcSpace/IfcQuantityVolume/GrossVolume
Room floor area	IfcSpace/IfcQuantityVolume/GrossFloorArea
Room shape	Fixed in 1 (no shape)
Room floor	IfcBuildingStorey
District_Land use category	Fixed in 2 (residential area)
District_Total number of buildings	Fixed in 1
Building_ID	IfcBuilding
Building_Total number of room facades of each building	IfcWall/*IsExternal*
RoomFacade_ID	IfcWall/GlobalId
Room_ID	IfcSpace/GlobalId
RF_Surface	Calculated directly by the ETL
RF_Strategic Noise Mapping value	Fixed in 0
RF_Balcony material	Fixed in −99
RF_Balcony width	Fixed in −99
External equivalent sound pressure level	*IfcSoundPressureLevelMeasure*
ElementFaçade	
Wall	IfcWallType/GlobalId
Number of wall id	IfcWalltype/GlobalId
Wall id	IfcMaterialLayerSet
Wall layer thickness	IfcMaterialLayer/LayerThickness
Wall layer density	IfcMaterialProperties/*MassDensity*
Element Building_ID	IfcBuilding/GlobalId
Element RoomFacade_ID	IfcWall/GlobalId
Element type	IfcWindow/IfcOpeningElement/IfcDoor/IfcWall
Element surface	Calculated directly by the ETL
Element id[a]	IfcOpeningElement/GlobalId IfcWindow/GlobalId

[a] The element id is obtained from each of the elements in the IFC, but then renamed to comply with the JSON requirements. In the case of the windows elements, the identifier (ID) is fixed according to the internal classification of the Acoustic Comfort tool for the different types of glazing, is a static value.

- **Walls classification**: the walls of the models must be correctly classified in order to distinguish between external and internal elements through the property *IsExternal*, obtained in the IFC file via the property set (Pset) *Pset_WallCommon.*
- **Sound pressure level**: data on the exterior equivalent sound pressure level must be included in the IFC. The *IfcSoundPressureLevelMeasure* class must be added in the BIM model for each external wall of the building to obtain this parameter in the IFC file, measured in decibels (dB). This exterior sound pressure level can be obtained in situ using measuring devices, or retrieved from the strategic acoustic map of the building district.
- **Material properties**: for each wall in the model, walls layers must be defined and the IFC must include information on the density of the materials for each of them. There is a parameter called *MassDensity* in the information related to the material class of each of the layers in the IFC standard. In case the value of this parameter is not available in the IFC, the calculations of the Acoustic tool cannot be carried out. For example, in the case of REVIT software, the IFC exporter does not allow the export of the thermal properties of materials, even if this information is included in the BIM model in REVIT. In this research context, this improvement of the IFC file with the necessary thermal parameters of the materials has been achieved with the use of the BIMtoBEPS tool [21]. This tool allows to obtain an enhanced IFC file by combining the original IFC with the information of the materials obtained in an Excel file that has been parsed and contains all the existing materials of the model.
- **Space boundary**: it is not necessary for the IFC file to contain the Second Level Space Boundaries of the spaces, as the surface of the elements of interest is automatically calculated by the ETL using geometrical information contained in the space faces, as well as in the wall instances touching those spaces. These geometric calculations have been performed because the surface of the space in contact with external walls cannot be correctly retrieved from an IFC file, even when the model has generated the Second Level Space Boundaries.

3.2. Retrieving BIM data for acoustic comfort calculation: the IFC4Acoustic parser

The ETL, IFC4Acoustic parser, developed as part of this research works as a facilitator to automatically, and more accurately, obtain the acoustic data already included in a BIM model. This ETL has been integrated as a service into the BIM-SPEED Cloud platform [45] from where the service can be launched automatically through an IFC file. This platform also stores the ETL output data (the JSONs files). In this integration, the ETL and the Acoustic Comfort tool are connected through an API connection and a Graphical User Interface (GUI) was created to serve as a BIM connector between the ETL and the platform. The main steps of the process follow to retrieving BIM data for acoustic comfort calculation are shown in Fig. 2. These steps are explained in detail in Fig. 3, which shows the sequence of processes and the interaction between different modules involved in the extraction, transformation, and loading of data for acoustic performance analysis. The following subsections describe the architecture, with the main functionalities of the tool, and the sequence process of the operation of the service.

3.2.1. Architecture

The architecture of the IFC4Acoustic parser service developed is shown in Fig. 4. This service is connected to a BIM cloud platform to obtain the input data to be sent to the acoustic comfort tool to perform the acoustic assessment. A detailed explanation of each module of the IFC4Acoustic parser service and the sequence of its use is given in the following subsections, together with an explanation of the main functionalities provided.

3.2.1.1. Modules of the IFC4Acoustic parser service. The IFC4Acoustic parser service is composed by 2 main modules: the Graphical User Interface (GUI) module and the ETL module. The ETL is the core of the system, including several essential sub-functions: (a) the IFC4Acoustic parser, which extracts the data from the IFC and transforms it to JSON format, (b) the API integration & Cloud data manager, which facilitates the connection between the ETL and the external tool for acoustic data processing and is responsible for uploading the results to the BIM cloud platform for storage.

- **Graphical User Interface** (GUI): a web/browser-based solution developed and operated as a BIM connector, enabling users to interact and launch the IFC4Acoustic parser ETL. Initially, the IFC file of the building is selected directly from the BIM-SPEED platform, and the ETL service is executed. This process automatically initiates the GUI, which then displays the name of the selected IFC file.
- **ETL** (Extract, Transform, Load): The ETL is connected with: the GUI to send alerts to the platform; to the Acoustic Comfort tool to send the filled JSON and get the results; and to the BIM SPEED platform to store/retrieve data. It is composed by:
  - o **IFC4Acoustic parser (Extract & Transform)**: that automatically retrieves information from an IFC file of a building, following a previously defined structure, in order to feed the API provided by the Acoustic Comfort tool, in JSON format. It has been developed using the Python programming language [46] and the open source *IfcOpenShell* library [47] to extract data from the BIM model. The structure of the ETL has been established on the basis of the Model View Definition (MVD) for information exchange in order to foster interoperability, as it is able to obtain data from different IFC files and defined according to the classes and Property Sets specified in the IFC standard. The ETL automatically parses a JSON file with the data extracted from the IFC. Some parameters are obtained directly from the IFC classes, as shown in Table 3, but others need geometric transformations and calculations using the data contained in the IFC.
  - o **API integration & Cloud data manager (Load):** this submodule facilitates the connection between the ETL and the Acoustic Comfort tool. The API integration handles the data exchange ensuring seamless communication and data transfer. The acoustic comfort tool performs the calculation with the input data provided and creates a new JSON file with the results of the acoustic assessment, returning the file to the ETL, which is programmed to wait for the results file in JSON. Once the API connected with the Acoustic Comfort tool returns the new JSON, this submodule of the ETL, the cloud data manager, launches a script (.EXE) to upload the files to the BIM-SPEED platform in the same folder location as the original IFC file.

3.2.1.2. Funcionalities. The main functionalities of the IFC4Acoustic parser service are the **automatic parsing of the IFC file to the JSON file**, functionality provided by the ETL module, and the obtention of the **calculation of the acoustic assessment of a building**, provided by the connection to the Acoustic Comfort tool.

3.2.2. Operation of the IFC4Acoustic parser service

The sequence of the process that is implemented by the service is detailed below and shown in Fig. 5, indicating the level at which it takes place, from the user level to the connection to the acoustic comfort tool.

1) Data acquisition & user interaction:
   a. Obtain the IFC file according the ETL requirements (explained in the BIM guidelines subsection 3.1.3.)
   b. Execute the IFC4Acoustic parser ETL by the user: Launch the service by running the IFC4Acoustic parser on the BIM-SPEED platform through the IFC file of the building, already uploaded to the platform.
2) ETL processing:
   a. Automatic parsing of IFC to JSON file:
      i. Auto extract the information from the IFC file.
      ii. Parse the data into the JSON file and prepare the processed data for transfer.
   b. Data transfer & acoustic assessment:
      i. Automatic connection to the Acoustic Comfort tool via API to send the results JSON file.
      ii. Automatic acoustic evaluation with the Acoustic Comfort tool.
   c. Upload the JSON results to the BIM-SPEED platform.
      i. The ETL retrieves the result of the calculation assessment of the Acoustic Comfort tool, the acoustic_calculation file in JSON.
      ii. Once the two JSON are available (the results of the parser IFC-JSON and the calculation assessment), the files are uploaded and stored automatically on the BIM-SPEED platform.

4. Results

4.1. Demonstration: the vitoria demo site

This section explains the application of the complete process of the IFC4Acoustic parser service tested in a real-life application.

4.1.1. The vitoria demo case

The demonstration site is located in the *Coronación* district in the city of Vitoria-Gasteiz, Spain, with the residential building ARCAYA5, built in 1950. It is a building with a ground floor and 4 upper levels and a 5th floor under the roof. The building shape is characterised by two main blocks, with two dwellings at the front and one dwelling at the back on

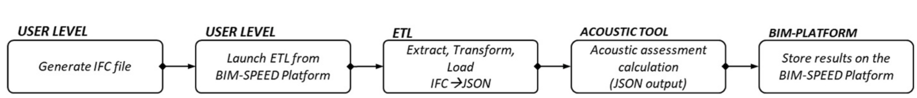

Fig. 2. Sequence of the process steps of the IFC4Acoustic parser service and its connection to the BIM-SPEED platform (own elaboration).

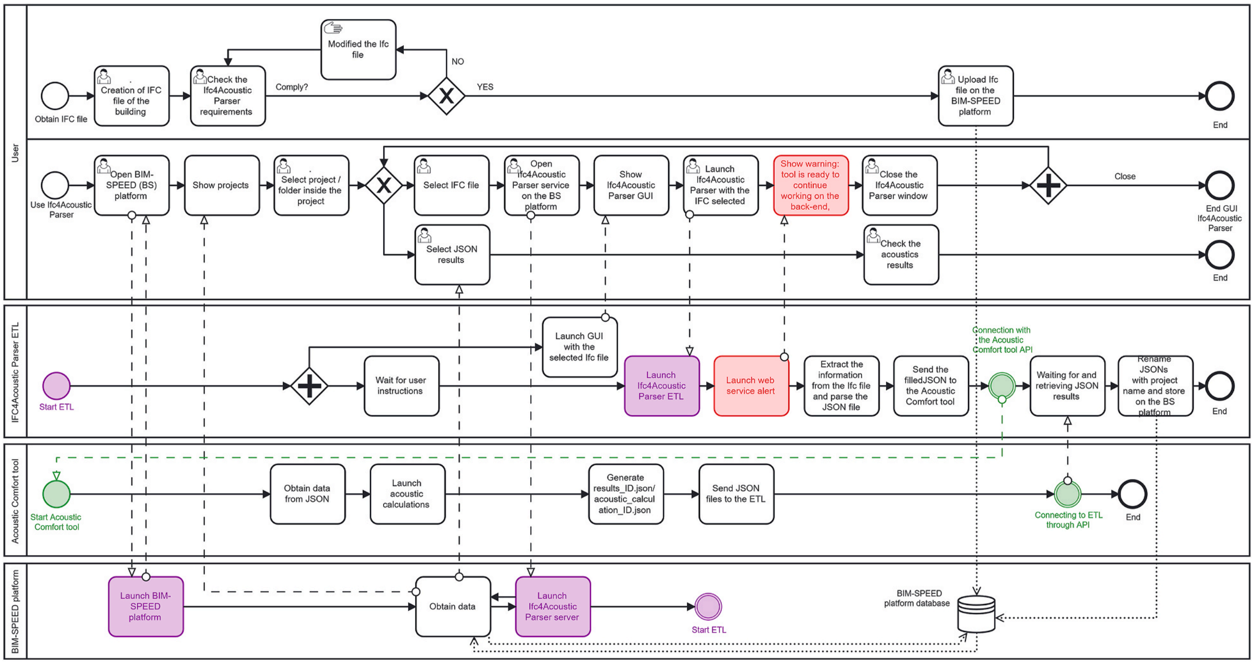

Fig. 3. Architecture flow diagram of the IFC4Acoustic parser service (own elaboration).

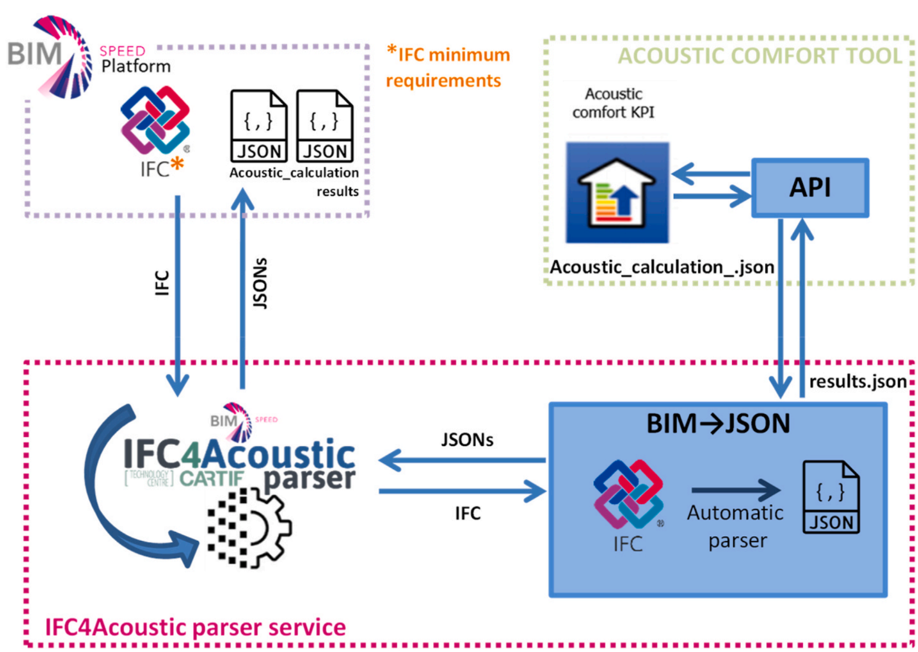

Fig. 4. Main architecture of the IFC4Acoustic parser service (own elaboration).

each of the 4 main floors, connected by a central corridor, which gives it a Latin I shape. The ground floor extends over the entire plot of the building. The sound pressure level of the street has been obtained from the noise map of the city, assigning a value of 57 dB on the main facade facing Manuel Díaz Arcaya street (North), an urban road, and assuming a value of 50 dB for the facades of the courtyard (South). These values have been integrated in the BIM model of the building. Fig. 6 shows an aerial view of the building and the acoustic analysis for agglomerations in Vitoria-Gasteiz (including roads, airport and industry) for L_{den} (Day-evening-night level) with the sources of noise available in Ref. [48].

In this specific case, the IFC file of the building did not comply with ETL requirements, the density (a thermal parameter) of wall materials was not included, stratigraphy data required for the calculation of the sound reduction index (R_w), as explained in section 3.1. In order to obtain a valid IFC format, an external tool, the BIMtoBEPS tool [21], was used to enhance the original IFC file with the thermal parameters of the wall layer materials. Once a correct IFC was generated, the next step was to launch the IFC4Acoustic parser service through the BIM-SPEED platform, explained in detail in the following sub-section. It should be mentioned that in order to carry out the validation of this case study some assumptions have been made, such as to assign a statically window identifier (ID) according to the internal classification of the Acoustic Comfort tool (a 5-level classification according to the type of window properties) for each of the window types detected in the building.

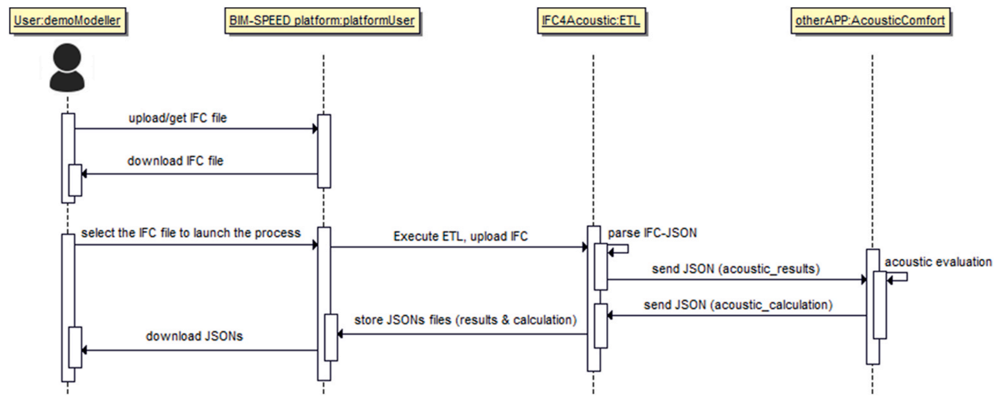

Fig. 5. Sequence diagram of the IFC4Acoustic parser service (own elaboration).

Fig. 6. Left: Aerial view of the building. Right: Map of a part of the Coronación district generated in QGIS software using the processed data. The layers have been obtained by processing the original data of the noise map (using L_{den} data) [48] of the city to improve geometry and metadata (own elaboration). Note: L_{den} is day–evening–night noise level.

4.1.2. IFC4Acoustic parser service

Through the BIM-SPEED Cloud platform [45], the user can launch the IFC4Acoustic parser service by selecting the correct IFC file of the building available into the platform, then the Graphical User Interface (GUI) of the tool is displayed with the file automatically uploaded. A few seconds after starting the tool, a warning message appears indicating that the tool has been successfully launched and the process continues running in the background without the need to keep the browser open. The parsing process can take from minutes to hours depending on the complexity of the model. Once the tool has completed the process, the results of the JSON with the parsing that will be sent to the Acoustic Comfort tool, and the JSON with the acoustic calculations returned by the tool, are uploaded directly to the BIM-SPEED platform.

In this case, the time taken to complete the whole process was 1 h and 38 min. The whole process consisted of: (i) retrieving the data from the IFC file and parsing it into the JSON file, (ii) connecting via API to the Acoustic Comfort tool, and (iii) waiting for the response data after performing the acoustic simulation. As a result, two JSON were obtained, the first one contains the information of the input data of the BIM model of the ARCAYA5 building, "*vitoria_results*" (Fig. 7), and the second one contains the results of the acoustic calculation, "*acoustic_calculation*" (Fig. 8). The data retrieved from the IFC file of the building are separated into *RoomFacade* and *ElementFacade*.

The possible options obtained as a result of the Acoustic Comfort tool can be in the range of (1) high level, (2) normal level, (3) acceptable level, and (4) values outside the criteria. In this case study the results obtained for the Vitoria demonstration case show that the range of the building falls within the *high level of building acoustic comfort: retrofit interventions on building envelope are not required.*

Fig. 7. Result obtained for "vitoria_result" in JSON format.

4.1.3. Validation of the data

The validation of the tool has been carried out by comparing the results obtained by the ETL with the data obtained with a manual process, focusing on the Level 1 of the building, detailed in Fig. 9, and has been divided into different steps. In this sense, it should be noted that the objective of the validation in this research is not to check for the

Fig. 8. Result obtained for "acoustic_calculation" in JSON format.

accuracy or representativeness of the acoustic comfort calculations from the existing Acoustic Comfort tool themselves, but to demonstrate that the proposed development in this work (IFC4Acoustic parser) is capable to: (i) adequately identify and retrieve the information available in the correctly generated BIM models (according to the IFC schema) that is required for the acoustic calculations, and (ii) automatically adapt this information to be fed into an existing Acoustic Comfort tool. Under such considerations, the ETL IFC4Acoustic parser has correctly identified the 90 rooms included in the model in six different levels (the ground floor, 4 levels above ground floor and a 5th floor under the roof). To do so, the ETL assigns each room a group number for each *Room Use* according to the established criteria, and then discards from the selection those rooms that are not valid, as described in detail in the BIM guidelines subsection. After discarding by use (corridors and bathrooms are excluded, the reason is that these are areas of short-term occupancy and transit) or because the room is in contact with an external wall, the remaining rooms are 48. The ETL retrieves the floor area and height of each of these 48 rooms to calculate the volume, among other parameters, as shown in Table 4.

An example of the manual inspection has been done for the rooms 01-C-03 KITCHEN and 01-C-05 LIVING ROOM. In the first room (01-C-03 KITCHEN) a window and a kitchen ventilation duct (a small element of 15 × 15 cm approx.) passing through the façade can be found in the IFC model, located on the same type of valid external wall. The other external wall in contact with the room is a party wall and is discarded by the tool. These two elements have been identified automatically by the ETL, as shown in Table 4. The second room selected (01-C-05 LIVING ROOM) only has a window, but it corresponds to 3 different elements of external walls, as detailed in Fig. 10.

The ETL is programmed to retrieve the different data needed to parse all the parameters needed by the JSON file, divided in *RoomFacade* and *ElementFacade* classification. Table 4 shows the data retrieved for the two rooms selected, according to the defined functions, where only 3 variables are added for the same function (e.g., *roomFacadeID**1**, roomFacadeID**2**, roomFacadeID**3***) because this is the maximum number of walls touching one of the selected rooms. The code has been limited to 6

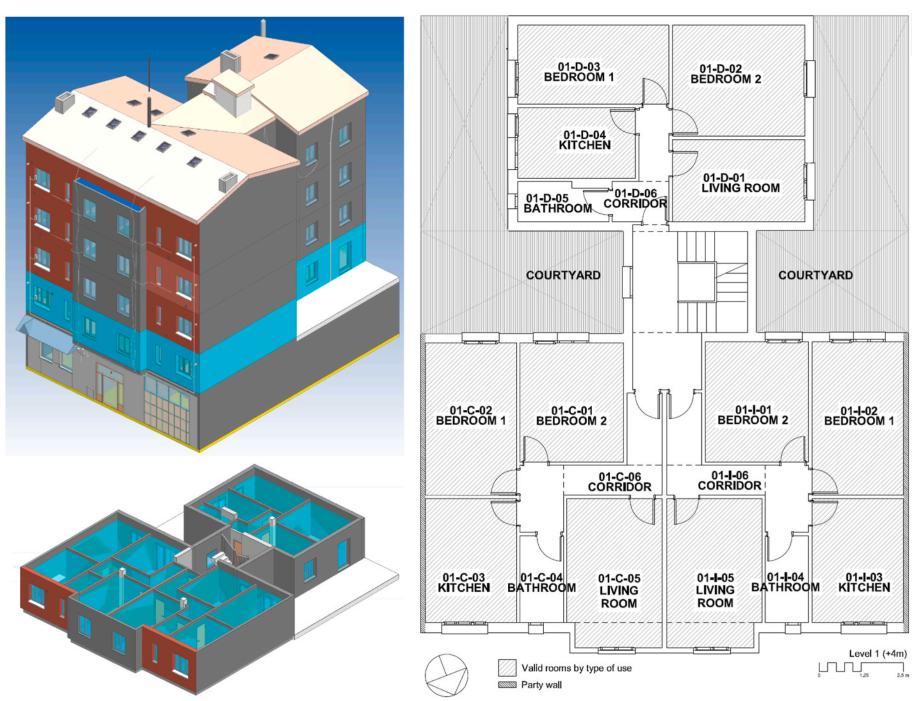

Fig. 9. Left: 3D view of the IFC file of the building with the Level 1 selected (up) and isolated with all the rooms included in the IFC file in blue (down). Right: Plant of the Level 1, obtained from the BIM model, with the 12 shaded rooms selected as valid by the ETL (own elaboration). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Automatic data obtained directly from the Python script created in the ETL for the functions defined (only the results of two rooms have been included in the table.).

Function	Data retrieved from room: KITCHEN 01-C-03	Data retrieved from room: LIVING ROOM 01-C-05
GUI	0Jt127oSz3ng1fJdcQ6vQZ	24XPPVcRT888GENurrM7jV
Manual inspection	1 window, 1 small element	1 window
BuildingId	3hrlOopGHBOelbHmZHNuFk	3hrlOopGHBOelbHmZHNuFk
FloorArea [m^2]	10.064	12.471
Height [m]	2.398	2.398
Id	2_lbwjVjTBUPY9ucXmfKAY	2_lbwjVjTBUPY9ucXmfKAO
Name	**KITCHEN 01-C-03:756255**	**LIVING ROOM 01-C-05:756261**
Volume [m^3]	24.133472	29.905458
RoomFacade		
roomFloor	A-P1	A-P1
roomShape	1	1
roomUse	2	2
roomFacadeBalconyMaterial1	−99	−99
roomFacadeBalconyMaterial2	–	−99
roomFacadeBalconyMaterial3	–	−99
roomFacadeBalconyWidth1	−99	−99
roomFacadeBalconyWidth2	–	−99
roomFacadeBalconyWidth3	–	−99
roomFacadeExternalEquivalentSoundPressureLevel1	57	57
roomFacadeExternalEquivalentSoundPressureLevel2	–	57
roomFacadeExternalEquivalentSoundPressureLevel3	–	57
roomFacadeID1	2Tm2MCHoD5_xuYA$gm8VP7	2Tm2MCHoD5_xuYA$gm8OJe
roomFacadeID2	–	2Tm2MCHoD5_xuYA$gm8OJh
roomFacadeID3	–	2Tm2MCHoD5_xuYA$gm8VP7
roomFacadeName1	Basic Wall:LKS_Ladrillo:1228874	Basic Wall:LKS_CE2:1225445
roomFacadeName2	–	Basic Wall:LKS_CE2:1225446
roomFacadeName3	–	Basic Wall:LKS_Ladrillo:1228874
roomFacadeStrategicNoiseMappingValue1	0	0
roomFacadeStrategicNoiseMappingValue2	–	0
roomFacadeStrategicNoiseMappingValue3	–	0
roomFacadeSurface1	6.52255999999995	2.15819999999987
roomFacadeSurface2	–	6.23480000000001
roomFacadeSurface3	–	0.22781000000002
roomFacadeWallTypeID1	3qxeuunYX7Yw4ATUk3Cfe0	2p_zptNOP77w3YyrmaWtHy
roomFacadeWallTypeID2	–	2p_zptNOP77w3YyrmaWtHy
roomFacadeWallTypeID3	–	3qxeuunYX7Yw4ATUk3Cfe0
ElementFacade		
relatedOpeningElementId1	2Tm2MCHoD5_xuYA_cm8VU4	2Tm2MCHoD5_xuYA_cm8OJg
relatedOpeningElementId2	2Tm2MCHoD5_xuYA$gm8VU7	–
relatedOpeningElementId3	–	–
relatedSElementArea1Facade1	0.0232257600000005	–
relatedSElementArea2Facade1	–	–
relatedSElementAreaOpeningGeometry1Facade1	0.0232257600000007	–
relatedSElementHeight1Facade1	0.152400000000002	–
relatedSElementHeight2Facade1	–	–
relatedSElementId1Facade1	2Tm2MCHoD5_xuYA$gm8VU7	–
relatedSElementId2Facade1	–	–
relatedSElementWidth1Facade1	0.152400000000001	–
relatedSElementWidth2Facade1	–	–
relatedWindowArea1Facade1	1.90539999999999	–
relatedWindowArea1Facade2	–	1.54
relatedWindowArea1Facade3	–	–
relatedWindowAreaOpeningGeometry1Facade1	1.90539999999999	–
relatedWindowAreaOpeningGeometry1Facade2	–	1.54
relatedWindowAreaOpeningGeometry1Facade3	–	–
relatedWindowAreaWindow1Facade1	1.90539999999999	–
relatedWindowAreaWindow1Facade2	–	1.54
relatedWindowAreaWindow1Facade3	–	–
relatedWindowHeight1Facade1	1.361	–
relatedWindowHeight1Facade2	–	1.1
relatedWindowHeight1Facade3	–	–
relatedWindowId1Facade1	2Tm2MCHoD5_xuYA$gm8VU4	–
relatedWindowId1Facade2	–	2Tm2MCHoD5_xuYA$gm8OJg
relatedWindowId1Facade3	–	–
relatedWindowWidth1Facade1	1.39999999999999	–
relatedWindowWidth1Facade2	–	1.4
relatedWindowWidth1Facade3	–	–

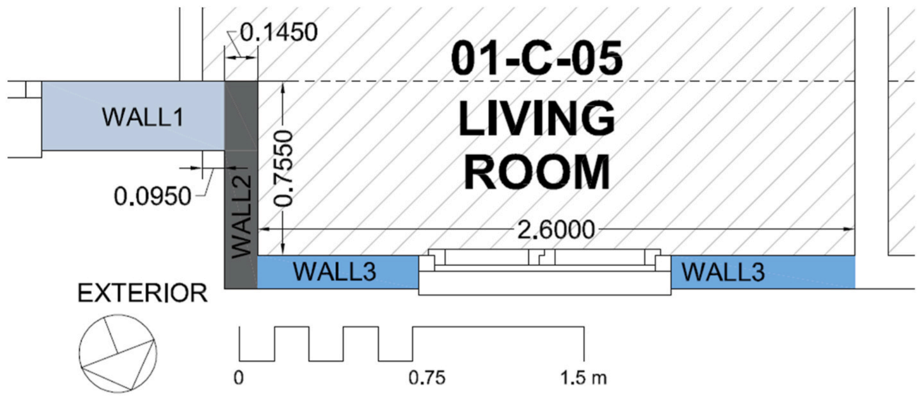

Fig. 10. Information and dimensions of the different exterior facades (walls) in contact with the room 01-C-05 Living Room (own elaboration).

possible variables that could be found in the same room of walls that meet the condition of being exterior, for example, in complex geometries. It is not realistic to have more than 6 different types of exterior walls contacting the same room, so this limitation has been established. The obtained results (Table 4) show that the 3 walls that are valid for space 01-C-05 LIVING ROOM have been correctly identified, as well as the element included in each wall. In this case the only additional element is a window (retrieved with the function *relatedWindowId1Facade2* = 2p_zptNOP77w3YyrmaWtHy), contained in WALL3 (recovered with the function *roomFacadeID2* = 2Tm2MCHoD5_xuYA$gm8Ojh.) The *roomFacadeSurface* (the area of the external façade touching a valid room) has been correctly calculated for each of the facades, even in complex cases such as the one in this room. The algorithm is programmed to calculate the surfaces of the spaces in contact with the exterior walls by triangulating the faces and summing their surfaces. To compare the results, detailed information on the surface area of each wall (the dimensions) is shown in Fig. 10.

Note that the walls named WALL2 and WALL3 in Fig. 10 have the same type of wall (2p_zptNOP77w3YyrmaWtHy), but the geometry is represented as two different elements in the IFC file, as shown in the results of *roomFacadeID1* and *roomFacadeID2*.This is the reason why they are detected as two different elements, each of them having a different IFC Globally Unique Identifier (IFC-GUID). The check calculation performed is shown in Table 5.

The validation performed for Level 1 has shown that the data have been correctly retrieved from the IFC file of the demonstration building for the two selected rooms, and this can be extrapolated to all other levels of the building, considering also that the classification of the building by room has been successfully performed. Note that the data obtained in Table 4 are focused on the selected rooms, the data provided by the tool in the JSON mapping at building level is not included in this table. Likewise, verifications have been made on the correct mapping by the ETL of the information of the types of exterior walls (5 different walls in this case), as well as their corresponding thickness and density data of each material (layer) included in each of the walls.

5. Discussion

5.1. Comparison with the common practice for the process of retrieving BIM data for acoustic comfort aalculation

The main steps followed to obtain the acoustic class results of a building, comparing both processes, the manual process of launching the acoustic assessment of the building versus the automatic process, are shown in Fig. 11. This scheme shows that the first step, creating the IFC file of the building, is the same in both processes, but specific considerations should be made in the case of the ETL. Comparing the automated process of retrieving BIM data for acoustic comfort calculation proposed in this research with the manual process without using the proposed solution, it can be seen that some of the steps to be followed in the process are similar, but with a significant amount of manual work to be done by the user in the first case. For the specific case study presented in this section for the demonstration building in Vitoria (Spain), and starting from the first step of the process, i.e., with the IFC model already created, the time taken by the ETL to generate the result was 1 h and 38 min (from the time the user launches the tool to the instant the results are obtained on the BIM-SPEED platform). In this case the manual time spent by the user is insignificant, as the user only needs to start the ETL execution. If the process of completing the input data required by the JSON file to launch the Acoustic Comfort tool had been done manually, it would have required at least 2 h of manual work by the user. This large amount of time is due to the fact that the user has to manually include the dimensions of the wall surfaces, checking them first in the BIM model, as well as the other information required by the JSON.

Based on the results obtained in Vitoria-Gasteiz after the application of the IFC4Acoustic parser, there are several advantages that can be gained from its use.

- The **reduction of time** in the acquisition of real building data using BIM, in the design of the renovation solution, and in the detailed engineering solution, identifying the acoustic class of the building;
- The **improvement of the accuracy of the results** compared to traditional methods, as no user iteration is required to obtain the necessary data (only for the correct generation of the IFC file used as input). The collection and transformation of the data is a process based on mathematical algorithms.

Table 5
Comparison of the data retrieved by the ETL and the manual calculation of the areas (surfaces) of the external walls of the room 01-C-05 LIVING ROOM.

Element	GUID	Width [m]	Height [m]	Area (width x height) [m^2]	roomFacadeSurface	Area retrieved [m^2]
WALL1	2Tm2MCHoD5_xuYA$gm8VP7	0.095	2.398	0.22781	roomFacadeSurface3	0.22781000000002
WALL2	2Tm2MCHoD5_xuYA$gm8OJe	0.145 + 0.755	2.398	2.1582	roomFacadeSurface1	2.15819999999987
WALL3	2Tm2MCHoD5_xuYA$gm8OJh	2.6	2.398	6.2348	roomFacadeSurface2	6.23480000000001

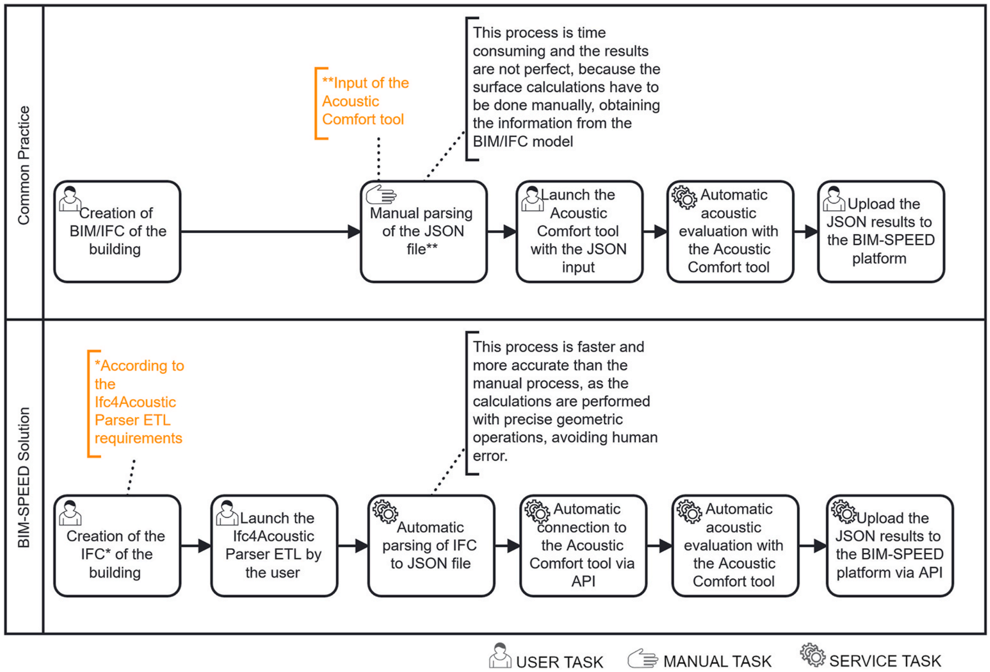

Fig. 11. Comparison of the manual data collection process for the acoustic comfort calculation with the proposed BIM-SPEED solution (own elaboration).

- The **reduction of renovation costs**, by having more accurate data on the current state of the building, more appropriate materials can be selected based on the results of the acoustic assessment.

This research demonstrates that the integration of IFC data with Acoustic comfort software, in an automatic way, significantly improves the accuracy of acoustic performance evaluations. In summary, this type of tools can be beneficial for technicians in charge of pre- and post-renovation evaluation of the building, where the results obtained can be used to improve the design of deep renovation projects.

5.2. Comparison with background literature on BIM for acoustic simulation

Although buildings are nowadays digitised through the use of BIM models, which provide detailed building information, the integration of this data into automated workflows to obtain acoustic performance calculations is still limited. Existing studies are mainly based on manual or semi-manual extraction and processing of BIM data for acoustic simulations, which can be time-consuming and error-prone. For example, having to select the materials for each wall or window in a pop-up screen, when this information is already contained in the BIM model, as is the case in the research conducted in Ref. [29]. In that work, in addition, the user has to select the room where the analysis is to be carried out manually, which is also the case in Ref. [35]. It has also been found that the connection to the IFC standard is very limited, forcing users to have specific BIM software, in most cases centred on REVIT [29–32,35].

This research makes several key contributions to the field of acoustic simulation, and addresses several limitations identified in previous studies. Firstly, it demonstrates the feasibility and benefits of automating the extraction and transformation of IFC data for use in acoustic performance calculations. Secondly, it provides a practical implementation of this automated process, showing its potential to improve accuracy and efficiency compared to manual methods. Finally, by integrating BIM data directly into the Acoustic Comfort tool, our approach enhances the overall capabilities of acoustic simulation tools, enabling the development of more advanced and reliable analyses of building performance. Furthermore, the use of IFC and JSON standards addresses the interoperability issues that often arise when using different data formats and tools.

5.3. Limitations and future work

The testing and validation of the tool in a real demonstration case has allowed to analyse the errors that appear as the complexity of the IFC models increases. Even though the tool has been proved to be useful, some improvements can be made in future versions, as some parameters have been fixed by default in this version of the tool, such as *District land use category* and the shape of the room façade. Considering that the IFC4Acoustic parser is still in a prototype phase, it is normal that there are still limitations in its use, as in is the case of the parameters that have been fixed by default, or due to the different casuistry that may be found in the IFC files used as input. Moreover, the tool needs an input IFC file that complies with the input requirements defined in the ETL, otherwise the results will not be valid, which is not really a limitation, but a constraint. Future work can focus on generating an automatic checker that reviews the input data according to ETL requirements.

Considering the limitations identified before, future research will focus on further automating the process by fixing as few parameters as possible. The IFC4Acoustic parser has been connected to the Acoustic Comfort tool to obtain the SPL inside the building, but this ETL can be adapted to operate with other acoustic tools, also to provide the transmission of noise produced indoors to an outdoor environment. Additionally, the ETL developed can be used in combination with other BIM-based tools, such as the tool presented in Ref. [4], to improve the algorithm by combining it with building acoustic comfort results provided by the IFC4Acoustic parser. This combination would improve the provided results, so that in addition to the existing regulation of the thermal parameters of the building envelope elements, acoustic aspects would also be considered.

6. Conclusions

Although BIM models have the potential to support a wide range of automated processes due to the amount of data they contain, the adoption of such automation is not yet widespread. In many current practices, data from BIM models is still often obtained manually by the user, i.e., having to review the BIM model for different dimensions or characteristics of elements, rather than taking full advantage of the semantic data embedded in these detailed digital models to automate workflows. In addition, interoperability problems in data exchange impact the automation of processes, representing one of the main challenges in developing BIM-based tools. This research has presented an innovative ETL solution that automates the retrieval and processing of the necessary data contained in a BIM model of a building, transforming it into the format required by acoustic simulation tools. Although the methodology was demonstrated using the Acoustic Comfort tool, the ETL is designed with flexibility, based on acoustic regulatory requirements, allowing adaptation to other tolls and workflows within the acoustic assessment domain. This ETL has been implemented as a service in a BIM Cloud platform, enabling the automatic storage of acoustic assessment results in JSON format, which specifically serves as both input and output for the Acoustic Comfort tool. The ETL has been tested and demonstrated in a relevant environment, i.e., at maturity level TRL6 (*Technology Readiness Level*), consisting of a residential building located in Vitoria-Gasteiz, Spain. The validation performed showed a relevant time reduction in the process, as well as an increased accuracy of the results due to a reduced user interaction to obtain the required data and more precise geometric operations for the acoustic comfort performance calculations.

The ETL solution developed in this research, the IFC4Acoustic parser, has proven to be beneficial in decision-making during the design phase of deep renovation projects by effectively overcoming the challenges of integrating BIM data into acoustic comfort calculations, while also ensuring data standardisation and interoperability through the use of the IFC standard. By automating the collection and processing of data required for acoustic calculations from BIM models based on the IFC standard, the ETL allows faster and more accurate results of the acoustic assessment of the building. This type of BIM-based tools enables technicians to reduce the time needed to perform an acoustic assessment, both before and after the building renovation. The IFC4Acoustic parser has been developed to obtain the required input data from the Acoustic Comfort tool, but it is a scalable and adaptable solution that can be adapted according to the data structure of other acoustic tools.

In conclusion, this research presents a significant advancement in the field of acoustic simulations by integrating IFC data with automated data processing. This approach not only improves accuracy, but also offers practical advantages for the development of other BIM-based applications, creating more efficient and reliable acoustic assessments to aid design and building renovation projects.

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CRediT authorship contribution statement

Sonia Álvarez-Díaz: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Sofía Mulero-Palencia:** Writing – review & editing, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Manuel Andrés-Chicote:** Writing – review & editing, Funding acquisition. **Milena Martarelli:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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